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PROSPECTS FOR USE OF MAGNETIC SEPARATOR FILTERS FOR TREATMENT OF CERAMIC SUSPENSIONS

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Use of magnetic separator filters with a granulated (in particular, polybead) working matrix for treatment of different suspensions, including ceramic suspensions, is proposed for removal of ferrous contaminants. A design of the cartridge type is examined as it allows rapidly performing frequent regeneration of the apparatus. The principal parameter of the charge medium — the equivalent pore diameter — is estimated based on a physical model of "fractional" parallelepiped cells and a formal model of the granulated medium pipes.

Granulated media such as charges of beads, pellets, particles of crushed material, and bodies of different shape are widely used as the working parts of different process equipment in many branches of industry. Such media with ferromagnetic properties (partially shown in Fig. 1) are used as a filter matrix (F-matrix) in magnetic separators, including (when the anticorrosion properties of the granules are ensured) for high-efficiency, precision cleaning of liquids and gases [1] in thermoenergetics, the chemical industry, metallurgy, etc.

In magnetization of the F-matrix, a much more intensive (in comparison to the magnetization field[2] created by the magnetizing system itself), high-gradient magnetic field is regenerated in its pores (primarily in the region of contact points of the granules) [1]. Favorable conditions are ensured in this way for capturing ferrous contaminants in passing the treated medium through the F-matrix.

In general, the range of process media for which F-separators of this type can be effectively used is relatively wide — there are numerous media in which ferrous contaminants are present in the form of particles from corrosion and wear of the equipment, scales, different metal inclusions that appear as a result of metal working, maintenance, servicing, crushing and grinding of raw material components, etc.

As the results of tests at Sokol (Dedovsk), Lira Keramika (Fryanovo), and Evrokeramika Works (Pechora) showed, use of these units is also promising in ceramics production for treating glazes, engobe, and slip to remove ferrous contaminants subject to magnetic precipitation.

One of these magnetic separator filters is shown in Fig. 2, that is, a high-speed apparatus with an internal magnetizing system (a block of permanent Nd – Fe – B magnets). This system makes it possible to create a totally closed magnetic circuit without magnetic field losses (there is no field outside of the working unit) together with combined (which guides the magnetic flux) pole pieces and F-matrix.

The cartridge principle of assembling the working unit of the apparatus with a toroid working chamber allows easily (manually) removing this toroid working chamber from the

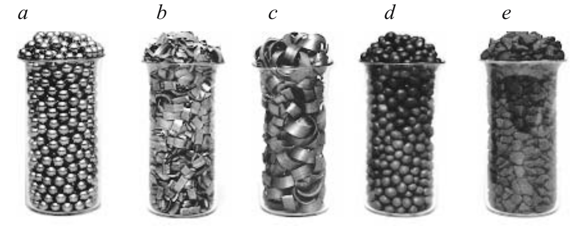

Fig. 1. Some types of granulated media used as porous F-matrices of units for magnetic treatment of liquids and gases: *a*) beads; *b* and *c*) crushed shavings (with a different degree of crushing)); *d*) pellets; *e*) crushed ferrite.

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[2] In analyzing the potential work capacity of different magnetic separators, the formal practice has been to characterize a unit by the value of the field (induction) strength H created by the magnetizing system or, no less frequently, on the surface of the precipitating element. Moreover, the magnetic force factor: H grad H, or in the case of bead granules, h grad h ($h \gg H$ is the generated magnetic field strength in the pores of the F-matrix) is a more objective characteristic of the magnetic-sorption capabilities. It is clear from this that a high value of H, even a hypervalue of H, a low value of grad H or grad h in the magnetic separator reduces to the minimum the possibility of self-cleaning of the apparatus.

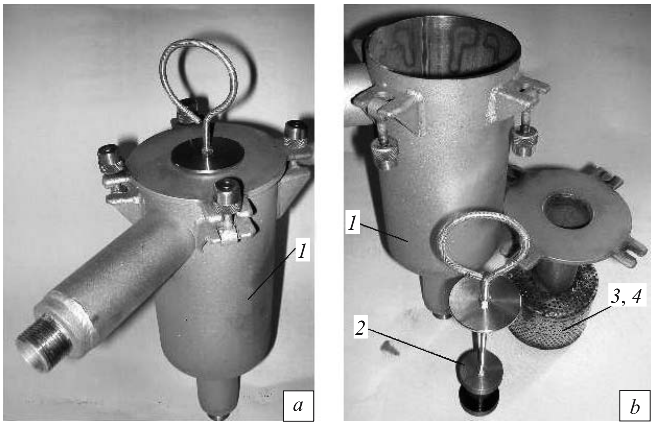


Fig. 2. Magnetic separator filter used for treating ceramic glaze, engobe, and slip assembled (*a*) and disassembled (*b*): *1*) body; *2*) internal magnetizing system with confined pole pieces; *3*, *4*) cartridge with polybead F-matrix in it.

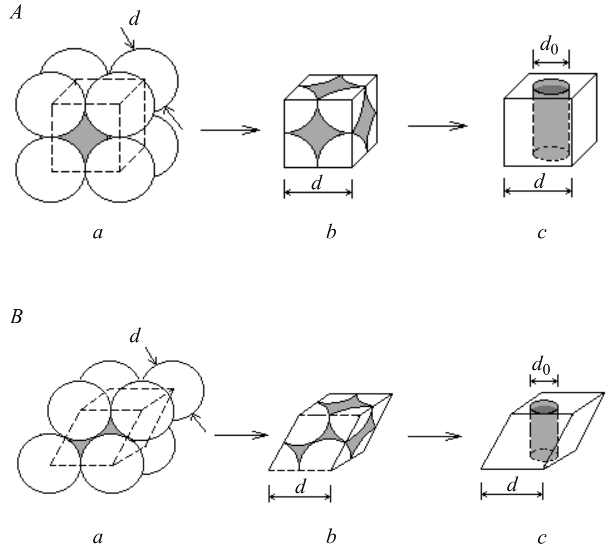


Fig. 3. Cubic (*A*) and square-rhombic (*B*) cells (*a*, *b*) and their transformed versions (*c*): *a*) cell indicated by the dashed outline in the structure of the beads (with real internal pore space); *b*) same, but "isolated" cell (the beads are arbitrarily cut out to fit the volume of the cell); *c*) modification of the "isolated" cell with equivalent (in volume) tube pore.

body of the apparatus together with the maganetizing system to totally preserve the sediment located in the F-matrix (to prevent its spontaneous outflow from the cartridge into the body of the apparatus). The magnetizing system is then removed from the cartridge chamber itself. As a consequence, the next operation of washing the polybead F-matrix is conducted without any magnetic field on it. The specially provided excess volume of the working chamber of the cartridge (in comparison to the volume of the F-matrix) allows easily "deforming" the initial shape of the F-matrix (for example, by overturning the cartridge), and perturbing the close contact zones of capture of contacting bead granules [1] and intensifying regeneration of the F-matrix.[3]

At first glance, the possibility of wide use of magnetic separators with a granular (polybead) F-matrix for treating ceramic suspensions is debatable due to the apparent smallness of the pores in charging the bead granules when they are in a totally random mutual position. To fully and definitively answer this question, it will be necessary to estimate the average diameter (for example, the equivalent diameter) of the pores in the F-matrix.

Such media with very "awkward geometry" of the structure are considered complicated for calculating the key parameters, in particular, the equivalent pore diameter d_0 of interest to us, as a function, for example, of the porosity of the medium ω and the equivalent diameter of the granules (in the given case, the bead diameter d).

Moreover, this problem is significantly simplified if [1 – 3]:

we use a progressive model of "fractional parallelepiped cells in characterizing the structure of the granulated medium;

we make the totally realistic assumption that any granulated charge medium with inherent random positioning of the beads is subject to average "ordering" followed by obtaining reliable average parameters;

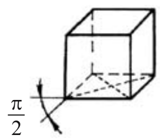
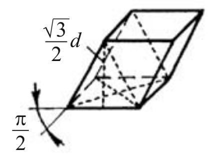
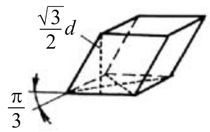
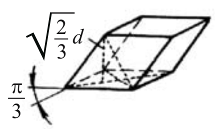
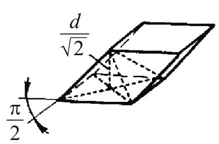
we take into consideration the relatively rigid "pendulum" self-regulation (in the region of the almost universal average value) of the porosity (packing density γ) of the porous medium formed in charging solid granules;

for the final calculation of d_0 in supplementing the cellular model, we use the calculation model of a porous medium which is "pierced" by a system of tube pores and ensures the same real porosity for the given granulated medium.

The model of the structure of the granulated medium in the form of a set of "fractional" parallelepiped cells implies original arbitrary structuring of this medium: it consists of elementary cells (Fig. 3) [1 – 3] whose apices are in the centers of eight neighboring beads. This means that they are "cut" from the granulated medium and in the most general case, are tilted parallelepipeds with an edge length equal to the diameter of the bead granules d (naturally, the direct version, i.e., the cubic cell shown in Fig. 3*A*, is a special case of this parallelepiped). As a consequence, the eight fractional parts "formed" by eight beads in such "cutting" enter any of the cells, which can only be demonstrated by a not very substantiated method at first glance. Moreover, in the case of "fractionation" of the beads, first, each cell will actually act as an equally justified elementary ministructure of the entire medium formed in this case according to a rigorously multiple "block" principle. Second, and no less important, the eight parts of the bead in any of these parallelepiped cells together constitute one whole bead.

[3] To visualize the sediment of contaminants trapped by the unit, it is regenerated (washed) in a separate container.

TABLE 1

Cell type, number of square and rhombic faces	Skeletal structure	Volume V_c, average surface area of face S_c, average cell length l, packing density γ, porosity ω, coordination number N_c, equivalent pore diameter d_0						
		V_c/d^3	S_c/d^2	l/d	γ	ω	N_c	d_0/d
Cubic (C-cell) 6 + 0		1.00	1.00	1.00	0.523 $\left(\frac{\pi}{6}\right)$	0.477	6	0.78
Square-rhombic (SR-cell) 4 + 2		0.87 $\left(\frac{\sqrt{3}}{2}\right)$	0.96	0.91	0.604 $\left(\frac{\pi}{3\sqrt{3}}\right)$	0.396	8	0.70
Rhombic (R-cell) 0 + 6		0.75 $\left(\frac{3}{4}\right)$	0.87	0.87	0.698 $\left(\frac{2\pi}{9}\right)$	0.302	10	0.58
Rhombic diagonal (RD-cell) 0 + 6		0.71 $\left(\frac{1}{\sqrt{2}}\right)$	0.87	0.82	0.740 $\left(\frac{\pi\sqrt{2}}{6}\right)$	0.260	12	0.53
Rhombic-square-diagonal (RSD-cell) 2 + 4		0.71 $\left(\frac{1}{\sqrt{2}}\right)$	0.91	0.78	0.740 $\left(\frac{\pi\sqrt{2}}{6}\right)$	0.260	12	0.55

This is especially clear in the example of five possible "discrete" cells (see Table 1 and Fig. 3) which, in consideration of their geometric features, are conveniently called parallelepiped cells based on the presence (advantageous presence) of square and rhombic faces. The invariable "capacity" of any cell allows very easily finding one of the key parameters — the granule packing density γ (and porosity $\omega = 1 - \gamma$) of any primarily "discrete," cell and consequently also the corresponding values of ω and γ of any structure of the granulated medium.

In a granulated medium with randomly positioned beads, at a sufficiently high coordination number (number of contact points of a granule with neighboring granules), despite the absence of long-range order, on the short-range level, different typical combinations of the mutual position of the granules are observed (see Fig. 1), including similar rigorously ordered packing. As a consequence, most of the cells in such a medium can be considered the same (but not "discrete") parallelepipeds, and the porosity or granule packing density can act as the criterion of "ordering" of the random structure of the granulated charge medium.

The porosity (granule packing density) of the granulated charge medium is characterized by the values $\omega \approx 0.4$ and $\gamma \approx 0.6$, and also granules of different size, even differing in size by two times. This indicates that the cell closest to square-rhombic is the basic cell of charges of solid granules (see Table 1 and Fig. 3*B*).

The model of a granulated medium "pierced" by a system of tube pores of diameter d_0 makes it possible to relatively simply determine this equivalent tube pore diameter in a granulated charge medium, which essentially boils down to calculating the equivalent tube pore diameter in the corresponding (square-rhombic) elementary cell. It is only necessary to know the cell volume V_c, the volume of its pore space $V_0 = V_c\,\omega$, and the average length l. The last can be found as the average value of three normals between opposite faces or, which is preferred, as the ratio of the cell volume to the average area of the face, for example, $l = d$ for a cubic cell, $l = 0.91d$ for a square-rhombic cell [1 – 3] (see Table 1 and Fig. 3). Then with the average section of the tube-pore

$$S_0 = V_c/l$$

we can calculate its diameter

$$d_0 = (4S_0/\pi)^{0.5}.$$

For the most porous (and the cubic cell most frequently involved for the different calculations [4]) cubic cell (see Ta-

ble 1 and Fig. 3*A*) for volume $V_c = d^3$, the pore space volume will be:

$$V_0 = V_c \omega = d^3 \omega.$$

Then the average section and diameter of a tube pore equivalent in volume can be determined as:

$$S_0 = V_0/d = \omega d^3 \cong 0.48 d^2;$$

$$d_0 = (4S_0/\pi)^{0.5} = 1.13\mathrm{d}\sqrt{\omega} \cong 0.78d,$$

including at the characteristic porosity value for this structure of $\omega \cong 0.477$ [1 – 3].

As for the square-rhombic cell of most interest to us (see Table 1 and Fig. 3*B*), for its characteristic parameter $V_c = \sqrt{3}\, d^3/2$, $V_0 = V_c \omega = \sqrt{3}\, d^3 \omega/2$ and $S_0 = V_0/l = 0.95 d^2 \omega \cong 0.38 d^2$, the equivalent tube pore diameter can be calculated just as easily:

$$d_0 = (4S_0/\pi)^{0.5} = 1.1\mathrm{d}\sqrt{\omega} \cong 0.7d,$$

including for the characteristic value here of $\omega = 0.396 \cong 0.4$ [1 – 3].

As a consequence, the equivalent pore diameter of the F-matrix of a magnetic separator, which is of the order of 70% of the bead diameter (usually $d = 8 - 10$ mm), is much larger than the real size of the contaminants of ceramic suspensions precipitated in them, that is, considering the predominant location of the precipitated contaminants in the capture near-contact zones (without overlapping of the pore flow area) ensures unimpeded passage of the treated suspensions.

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